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Summary In 1991 the UK Audit Commission produced energy performance indicators for hospitals based on the type of care provided. However, an analysis of over 100 hospitals throughout the United Kingdom has found the type of care provided to have relatively little effect on the energy performance of hospitals. Although other factors influenced energy use to some degree, the major factor affecting performance was found to be the plan of the hospital, as this influenced the amount of mechanical ventilation required. Modern mechanically ventilated hospitals were found to typically use 40% of their total electricity consumption in fan power, equating to 80 kWh m^{-2} purely due to fans. This paper presents a suggested set of new performance indicators based on the percentage of floor area which is ventilated mechanically.

Hospital energy performance: New indicators for UK National Health Service estate

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List of symbols

y_{EPI}	Electricity performance indicator for site
y_{FFPI}	Fossil fuel performance indicator for site
$x_{\%MV}$	Percentage floor area ventilated mechanically

1 Introduction

Government expenditure on the UK National Health Service accounts for £30 billion per annum. The largest proportion of this value, 60–70%, is spent on staffing costs. Energy represents the fourth largest cost after drugs and medical purchases. Energy costs equate to over £300 million per annum, with more than 50% spent on electricity[1].

United Kingdom (UK) energy use amounts to over 230 million tonnes oil equivalent[2]. Primary energy use due to UK hospitals accounts for just over 1% of this amount. This investigation aims to improve the understanding of how this energy is used. To obtain representative information and data for the health service, over 150 hospitals were considered, that is approximately 10% of the hospitals in England and Wales.

2 Existing data on the energy performance of hospital buildings

In 1991 the Audit Commission published performance indicators for hospitals based on a study of 200 hospitals conducted during the preceding years[3]. The Commission's performance indicator was a measure of energy consumption in terms of GJ per 100 m^3 per annum. The Audit Commission separated hospitals by type. Large acute hospitals were suggested as the most electricity-intensive area in the NHS due to their greater activity levels in terms of medical treatment. Long-stay hospitals had the lowest electricity consumption of all the types because their medical treatment is less vigorous. Fossil fuel consumption seemed to be slightly higher in acute hospitals, perhaps due to small steam requirements for medical treatment.

However, closer examination of the Audit Commission's data revealed that some hospitals were using over three times the amount of electricity suggested by the norms, and that fossil fuel consumption in certain cases was twice that implied. This suggests that factors other than type were affecting the results dramatically.

3 Results of annual energy consumption study

From the data on 150 hospitals, variations in the annual electricity and fossil fuel consumption were analysed in terms of possible factors that might affect the specific consumption. Hospital type, age and building form were examined to enable the variations in energy use due to these factors to be quantified. The electricity performance indicator (EPI) and fossil fuel performance indicator (FFPI) of each hospital were identified and are shown in Figures 1 and 2 respectively[4]. The performance indicators are expressed in terms of kWh m^{-2}. To convert a performance indicator in GJ per 100 m^3 to kWh m^{-2}, assuming an average ceiling height of 2.9 m, multiply by 8.1.

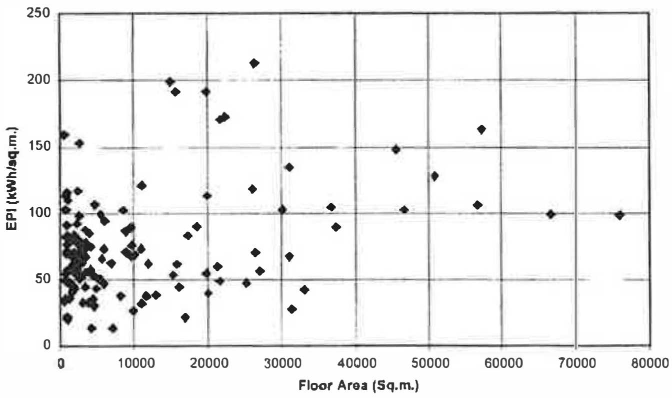

Figure 1 Electricity performance indicators for hospitals 1994/95

3.1 *Effect of building type on energy consumption*

The type of building had an effect on the EPI in that large acute hospitals had an average EPI, at 97 kWh m^{-2}, substantially above those of small acute and long-stay hospitals, at 66 and 70 kWh m^{-2} respectively. Also, much greater variations in electrical performance occurred in large acute hospitals when compared to small acute and long-stay hospitals. The coefficients of variation were 53% and 38% respectively. Part of the reason for this wide variation and higher electrical perfor-

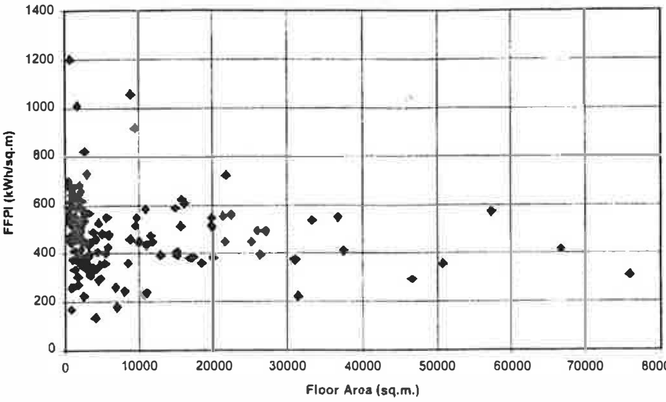

Figure 2 Fossil fuel performance indicators for hospitals 1994/95

mance indicator for large acute hospitals was the presence in the statistics of a number of modern deep-plan mechanically ventilated hospitals. These hospitals had very high electricity consumption per square metre, as they require fans to ventilate the core of the building.

The average fossil fuel performance of small acute, long-stay and large acute hospitals were similar, at 493, 467 and 470 kWh m^{-2} respectively. However, much larger variations in the fossil fuel performance occurred in small acute and long-stay hospitals, i.e. coefficients of variation of 33% and 39% respectively, as compared with the large acute hospitals' coefficient of variation of 22%. The wide variation in the fossil fuel performance of small acute and long-stay hospitals was due to a higher number of older hospitals with poorly maintained buildings and heating systems.

3.2 Effect of hospital age on energy consumption

The electrical consumption of modern large acute hospitals was higher, at 149 kWh m^{-2}, than that of other large acute sites, at 75 kWh m^{-2}. Likewise, the electrical consumption of modern small acute/long-stay hospitals was higher, at 96 kWh m^{-2}, as compared with 65 kWh m^{-2} for older hospitals of this type. This indicated that more stringent building regulations had little effect on electricity use, as any improvement in plant performance had been countered by an increase in services.

Modern large acute hospitals used more fossil fuel, at 558kWh m^{-2}, than older hospitals of this type, at 454 kWh m^{-2}. Although there could be little doubt that energy consumption was minimised by high levels of insulation of the perimeter walls, floors and roof, many other factors seemed to affect the fossil fuel performance indicators apart from the building fabric. For example, the level of heat recovery from mechanical ventilation systems and the type of heating medium seemed to be more influential factors. In contrast to large acute hospitals, modern small acute/long-stay hospitals used less fossil fuel at 404 kWh m^{-2} compared to 489 kWh m^{-2} in older hospitals of the same type.

3.3 Effect of mechanical ventilation on energy consumption

The plan of the hospital was the major factor influencing the energy consumption of modern hospitals. Deep-plan hospitals were classified as those where the core of the building was more than 8 m from the skin. Deep-plan hospitals, whatever their type, used far more electricity than their narrow-plan counterparts due to the need to ventilate the core of the building using mechanical ventilation. This was illustrated by deep-plan large acute hospitals using 182 kWh m^{-2} as compared with 83 kWh m^{-2} for narrow-plan hospitals of this type. Similarly, deep-plan small acute/long-stay hospitals used more electricity, at 119 kWh m^{-2}, than 65 kWh m^{-2} for narrow-plan hospitals of this sort. Narrow-plan hospitals tended to use less energy as they were aided by natural ventilation.

Conventional thinking was that the building surface-to-volume ratio should be minimised in order to reduce heat loss through the building's fabric. However, this had led to deep-plan buildings. These deep-plan hospitals often used more fossil fuel than their narrow-plan equivalents, as the heat was not recovered from the ventilation air. For instance, deep-plan large acute hospitals used an average of 554 kWh m^{-2} as compared with 453 kWh m^{-2} for narrow-plan hospitals of this type.

4 Analysis of factors influencing annual energy use

4.1 Alternative electricity performance indicators for hospitals

The effect of the level of mechanical ventilation on electricity use was further analysed by plotting the EPIs of 15 modern hospitals against the percentage floor area mechanically ventilated, as shown in Figure 3. The percentage of floor area mechanically ventilated was estimated from plans of the hospitals. It can be seen that the EPI rises with the percentage of floor area mechanically ventilated. This illustrates how the electricity consumption of modern hospitals is largely governed by the need to provide mechanical ventilation to deep-plan buildings. The occurrence of a linear relationship between the EPI and the percentage of floor area mechanically ventilated, was investigated with the following equation generated:

$$y_{EPI} = 1.99x_{\%MV} + 83.7 \quad (1)$$

where y_{EPI} is the electricity performance indicator for the site, and $x_{\%MV}$ is the percentage floor area ventilated mechanically.

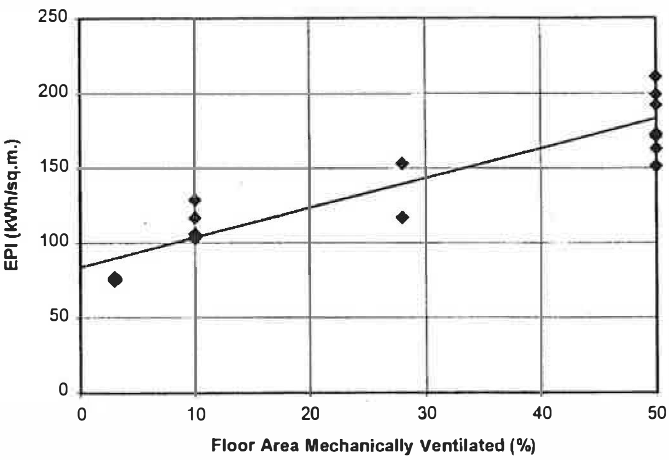

Figure 3 EPI versus proportion of floor area ventilated mechanically (Points are actual data; line is regression fit.)

As equation 1 was based on a sample of hospitals, the statistical significance of the equation was tested. It was found with a 95% degree of certainty that there was a relationship between the EPI and percentage floor area mechanically ventilated. Equation 1 had an r^2 value of 0.85, reflecting a reasonably good straight-line fit for the data. This value means that 85% of the variation in the electricity performance could be explained in terms of the percentage of floor area mechanically ventilated. The remaining 15% of variation was thought to be due to the type of health care provided, among other factors. The standard error in the EPI was found to be 17.83 kWh m^{-2}, producing a coefficient of variation of between 10 and 21%, depending on the percentage floor area mechanically ventilated.

Table 1 shows suggested typical performance indicators for the electricity performance of modern hospitals with between 0 and 50% of floor area mechanically ventilated, derived from equation 1. Although equation 1 could be used to predict EPIs for modern hospitals with more than 50% of their floor area mechanically ventilated, it is unsafe to extrapolate from statistical data. Furthermore, this accounts for a very small proportion of modern hospitals. Hospitals achieving good practice would use less than the typical values suggested.

Table 1 Alternative electricity performance indicators (EPI) for modern hospitals

Proportion of floor area ventilated mechanically(%)	Typical EPI (kWh m^{-2})
0	84
10	104
20	124
30	143
40	163
50	183

4.2 Alternative fossil fuel performance indicators for hospitals

The effect of the level of mechanical ventilation on fossil fuel use was further analysed by plotting the FFPIs of modern hospitals against the percentage floor area mechanically ventilated, as shown in Figure 4. It can be seen that the FFPI rises with the percentage of floor area mechanically ventilated, although at a more gradual rate than for electricity. This illustrates how the fossil fuel consumption of modern hospitals was also influenced by the need to provide mechanical ventilation to deep-plan buildings. The occurrence of a linear relationship between the FFPI and the percentage of floor area mechanically ventilated was investigated, and equation 2 generated:

$$y_{FFPI} = 3.53\, x_{\%MV} + 366.5 \qquad (2)$$

where y_{FFPI} is the fossil fuel performance indicator for the site and $x_{\%MV}$ is the percentage floor area mechanically ventilated.

It was established with a 95% degree of certainty that there was a relationship between the FFPI and the percentage floor area mechanically ventilated. The value of r^2 for equation 2 is 0.47. This value meant that 47% of the variation in the fossil fuel performance could be explained in terms of the percentage of floor area mechanically ventilated. The remaining 53% of variation was thought to be due to many factors such as the efficiency of the heating system, level of heat recovery employed, etc. The greater disturbance of fossil fuel performance by other factors made the equation a less accurate predictor than that for electricity. The standard error in the FFPI was found to be 82.45 kWh m^{-2}, producing a coefficient of variation of between 15 and 23%, depending on the percentage floor area mechanically ventilated.

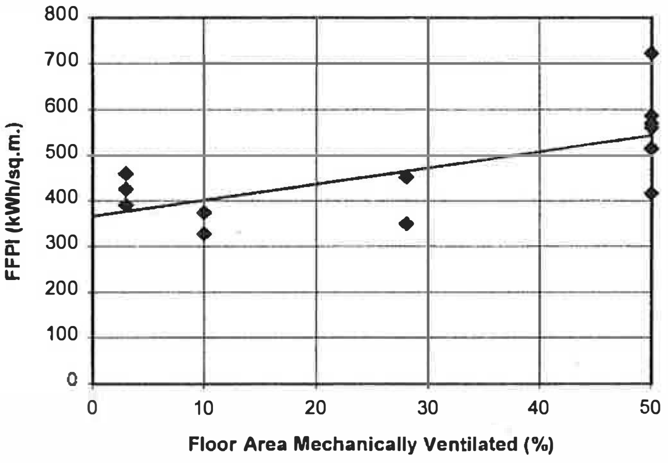

Figure 4 FFPI versus proportion of floor area ventilated mechanically (Points are actual data; line is regression fit.)

It can be seen in Table 2 that the suggested FFPIs increase as the percentage floor area mechanically ventilated increases from 0 to 50%. However, changes due to the level of mechanical ventilation are less pronounced when compared with electricity consumption. Similarly to the case of electricity, although equation 2 could be used to predict FFPIs for modern hospitals with more than 50% of their floor area mechanically ventilated, it is unsafe to extrapolate from statistical data.

Table 2 Alternative fossil fuel performance indicators (FFPI) for modern hospitals

Proportion of floor area ventilated mechanically(%)	Typical FFPI (kWh m^{-2})
0	367
10	402
20	437
30	472
40	508
50	543

4.3 Comparison with Audit Commission performance indicators

To illustrate the differences between these new performance indicators and those of the Audit Commission, a hospital with 50% of its floor area mechanically ventilated is discussed by way of example. Such a hospital achieving average performance would have an EPI of 183 kWh m^{-2}. If this hospital had been analysed using the Audit Commission's yardsticks it would have been expected to have an EPI of approximately 73 kWh m^{-2} (9 GJ per 100 m^3), bearing no relation to the reality of the hospitals' electricity consumption. This type of scenario has led many hospital engineers to discard the Audit Commission's yardsticks, as it has made their particular hospital appear inefficiently in terms of electricity usage, when in fact its higher consumption was due to the original design of the building. It is hoped that these new yardsticks will at least give hospital users a more accurate reflection of the electrical performance of their buildings.

The alternative fossil-fuel performance indicators for hospitals take account of the form of the building and are hence an improvement over the current benchmarks. The average FFPI for modern deep-plan hospitals, i.e. 50% of floor area mechanically ventilated, was 2% above the 535 kWh m^{-2} (66 GJ per 100 m^3) proposed by the Audit Commission for large acute hospitals. However, the average FFPI for modern narrow-plan naturally ventilated hospitals, i.e. typically 10% of floor area mechanically ventilated, was 25% below the Audit Commission's yardsticks for large acute hospitals. This illustrates how the form of the building has been taken into account.

5 Conclusions

An analysis of 150 hospitals found that the type and age of a hospital had comparatively little effect on its energy performance. The major factor influencing energy performance was found to be the plan of the hospital, since this influenced the amount of mechanical ventilation required. Deep-plan mechanically ventilated hospitals used up to twice as much electricity per square metre as compared with narrow-plan naturally ventilated hospitals. They also consumed up to 25% more fossil fuel per square metre when heat recovery was not employed. The analysis of hospital energy performance has enabled new electricity and fossil fuel performance indicators to be suggested which take into account the design of hospital buildings.

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